The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2060-21

Advanced School on Non-linear Dynamics and Earthquake Prediction

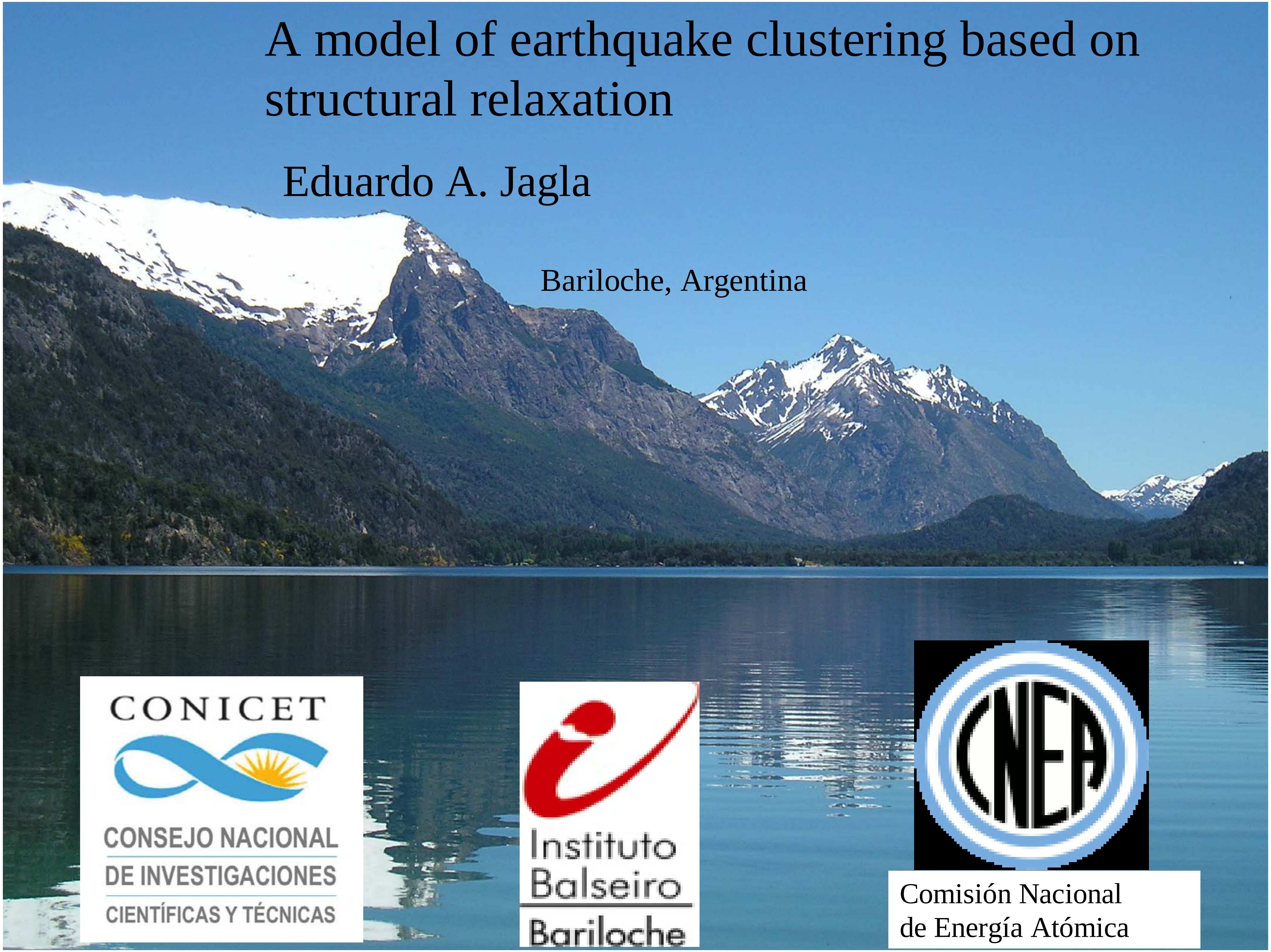
28 September - 10 October, 2009

A model of earthquake clustering based on structural relaxation

Eduardo A. Jagla
Centro Atomico Bariloche
Argentina

jagla@cab.cnea.gov.ar

Strada Costiera 11, 34151 Trieste, Italy - Tel.+39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it


A model of earthquake clustering based on structural relaxation
Eduardo A. Jagla
Bariloche, Argentina
CONICET
CONSEJO NACIONAL DE INVESTIGACIONES CIENTÍFICAS Y TÉCNICAS
Instituto Balseiro Bariloche
CNEA
Comisión Nacional de Energía Atómica

Overview:

- Three fundamental pieces of the phenomenology of earthquakes

- There is no simple statistical model that reproduces the all three

- Presentation of an old (spring-block) model with a new ingredient that explains the three features.

- (two of them today, third one on friday)

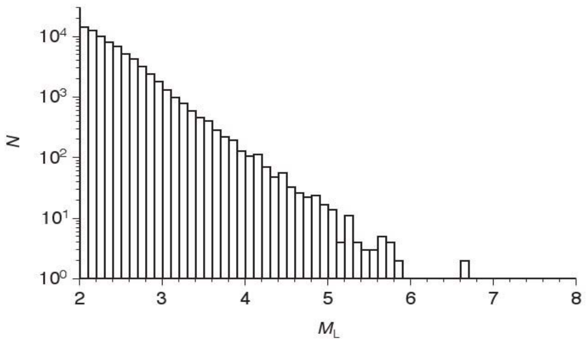
Three landmarks in the Phenomenology of Earthquakes

Gutenberg-Richter law:
$N(M) \sim 10^{-bM}$

Omori-Utzu law of aftershocks:
$N(t) \sim 1/(t+t_0)^p$

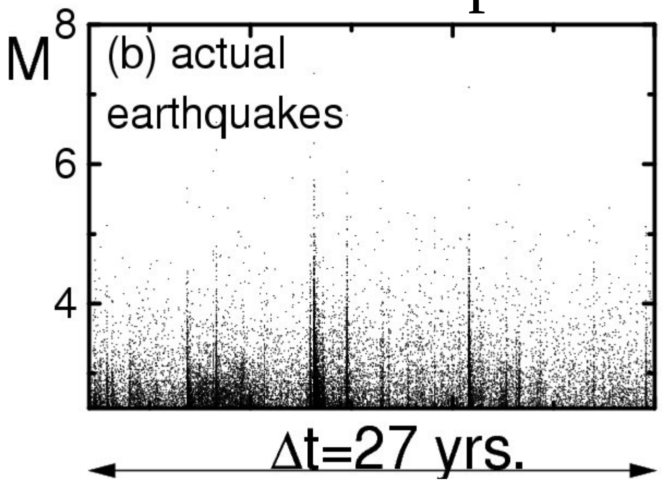
Rate-and-state equations

b~1

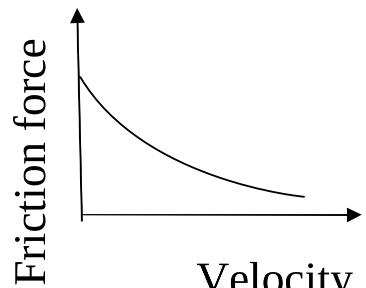


(Southern California data)

p~1



In particular:



"Velocity weakening"

Spring-blocks models
(i.e., Burridge-Knopoff (BK),
Olami-Feder-Christensen (OFC))
...

Gutenberg-Richter law:
$N(M) \sim 10^{-bM}$

(requires tuning
of parameters
for realistic b)

Omori-Utzu law of aftershocks:
$N(t) \sim 1/(t+t_0)^p$

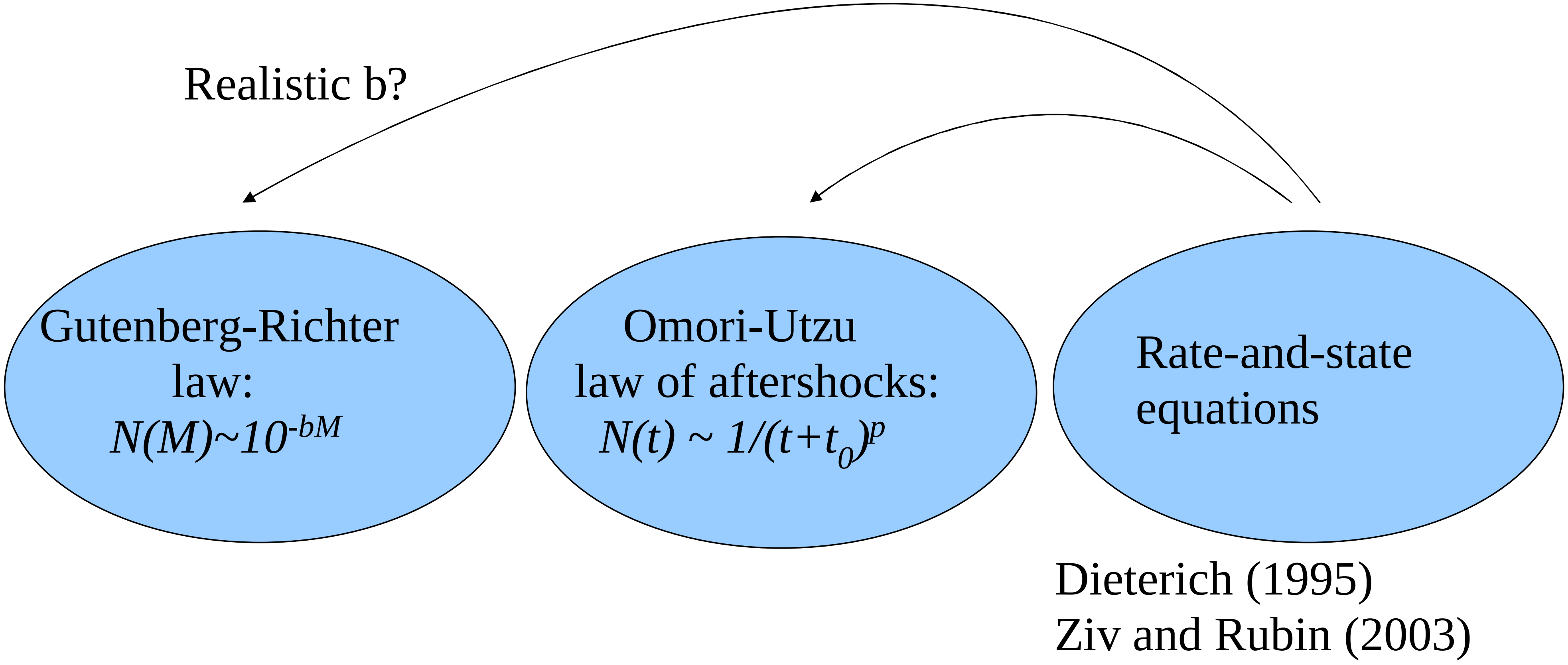
Rate-and-state equations

Spring-blocks models
+ad hoc stress relaxation
(Ben Zion an Rice 1993
Hainzl et al 1999,2000)

Gutenberg-Richter law: *$N(M)$~10^{-bM}*

Omori-Utzu law of aftershocks: *$N(t) \sim 1/(t+t_0)^p$*

Rate-and-state equations


Realistic b?
Gutenberg-Richter law: $N(M) \sim 10^{-bM}$
Omori-Utzu law of aftershocks: $N(t) \sim 1/(t+t_0)^p$
Rate-and-state equations
Dieterich (1995)
Ziv and Rubin (2003)

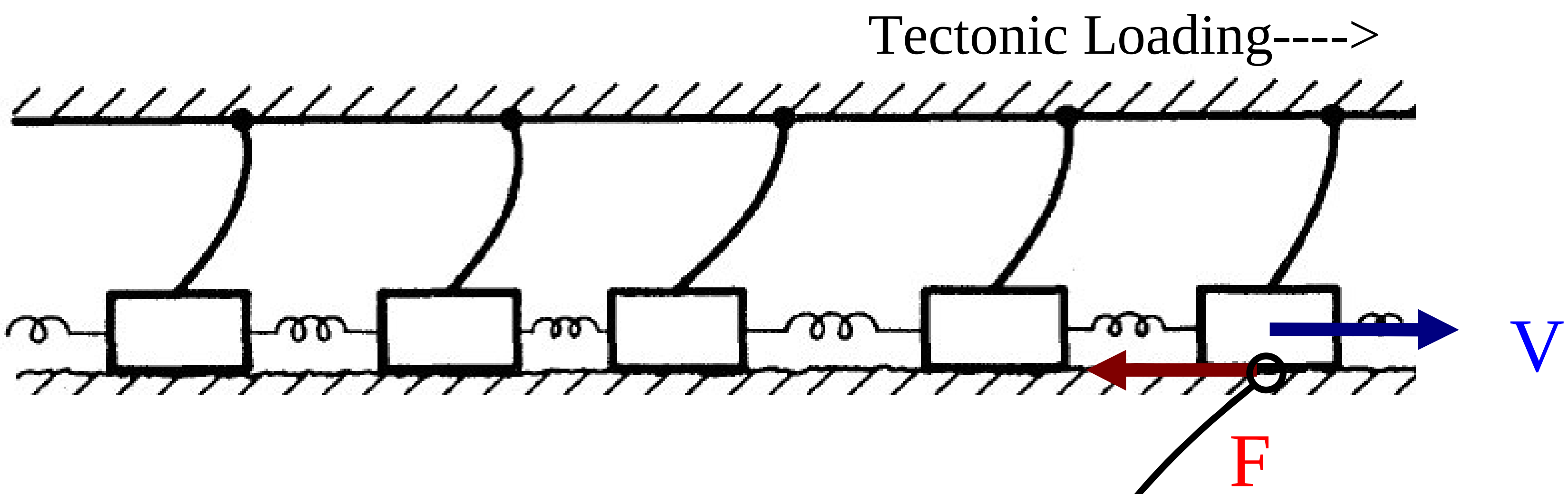
Spring-block model plus
Structural Relaxation

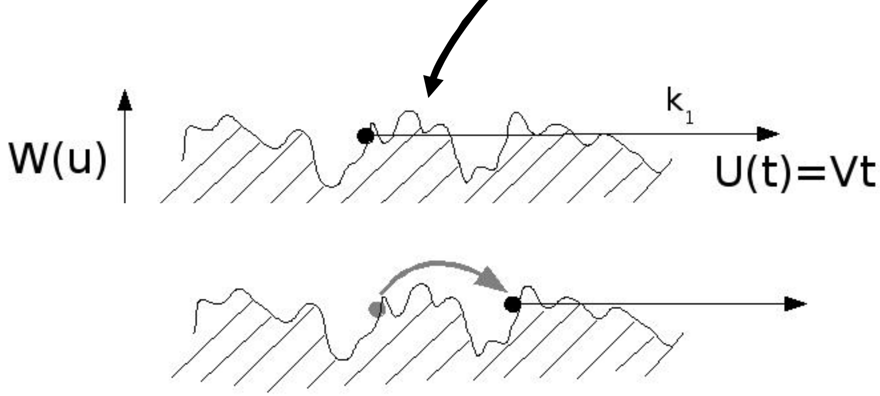
Gutenberg-Richter
law:
$N(M) \sim 10^{-bM}$

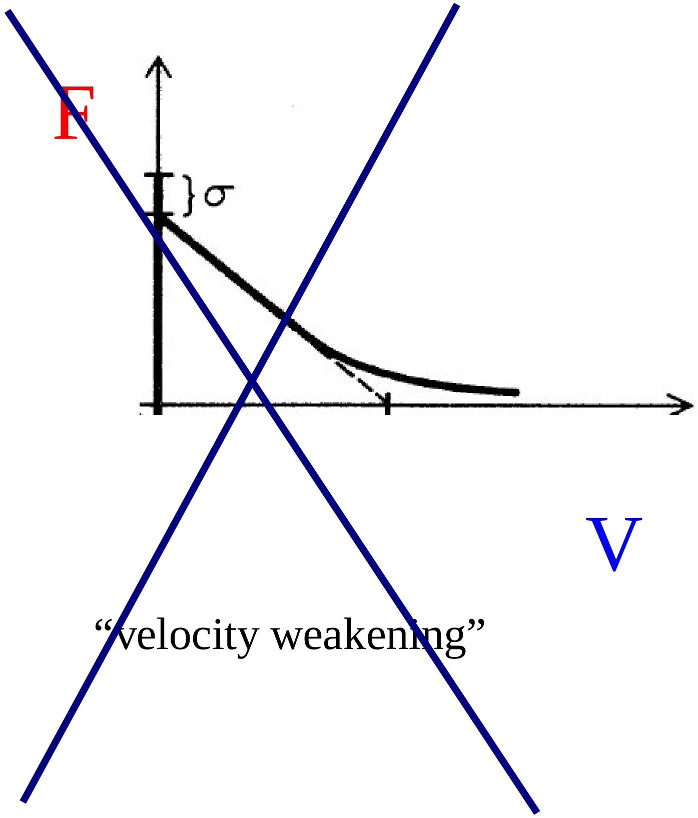
Omori-Utzu
law of aftershocks:
$N(t) \sim 1/(t+t_0)^p$

Frictional behavior
compatible with

Rate-and-state
equations



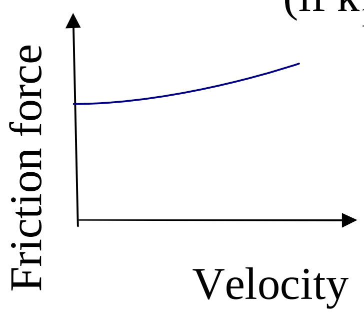


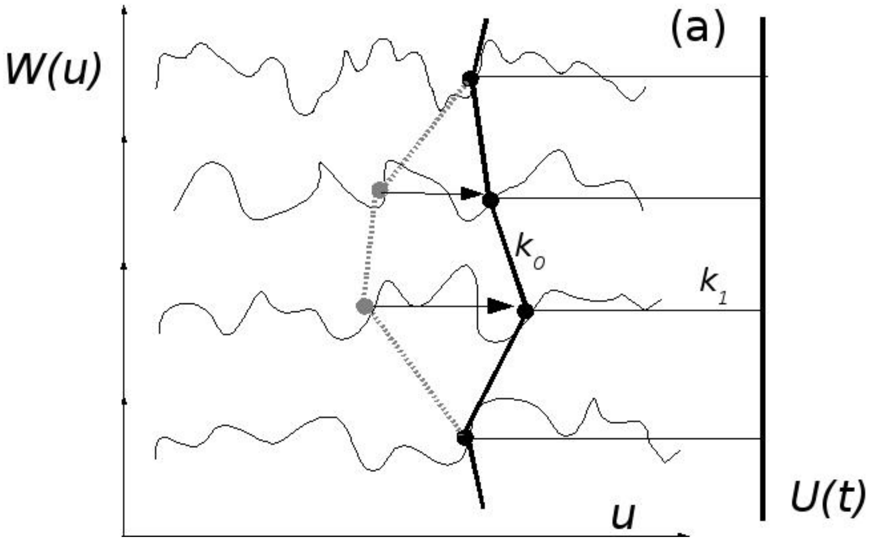


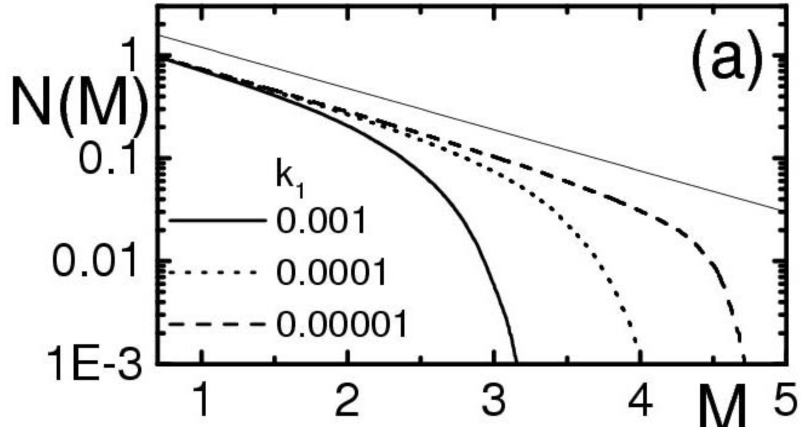
"velocity weakening"

"slip weakening"

(if k_1 sufficiently small)



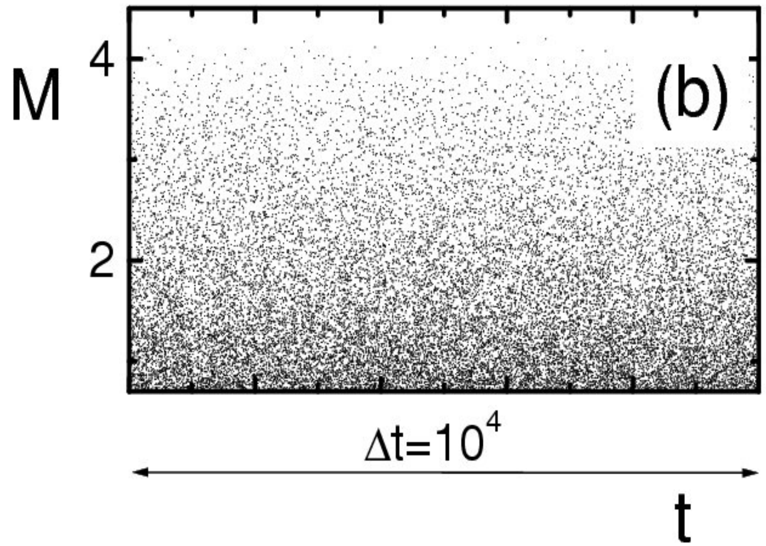




GR law, but unrealistic
exponent (0.4, against ~1)

$$E = \sum_{i,j;i',j'} \frac{k_0}{2} (u_{i,j} - u_{i',j'})^2 + \sum_{i,j} \frac{k_1}{2} (U(t) - u_{i,j})^2 + \sum_{i,j} W_{i,j}(u_{i,j})$$

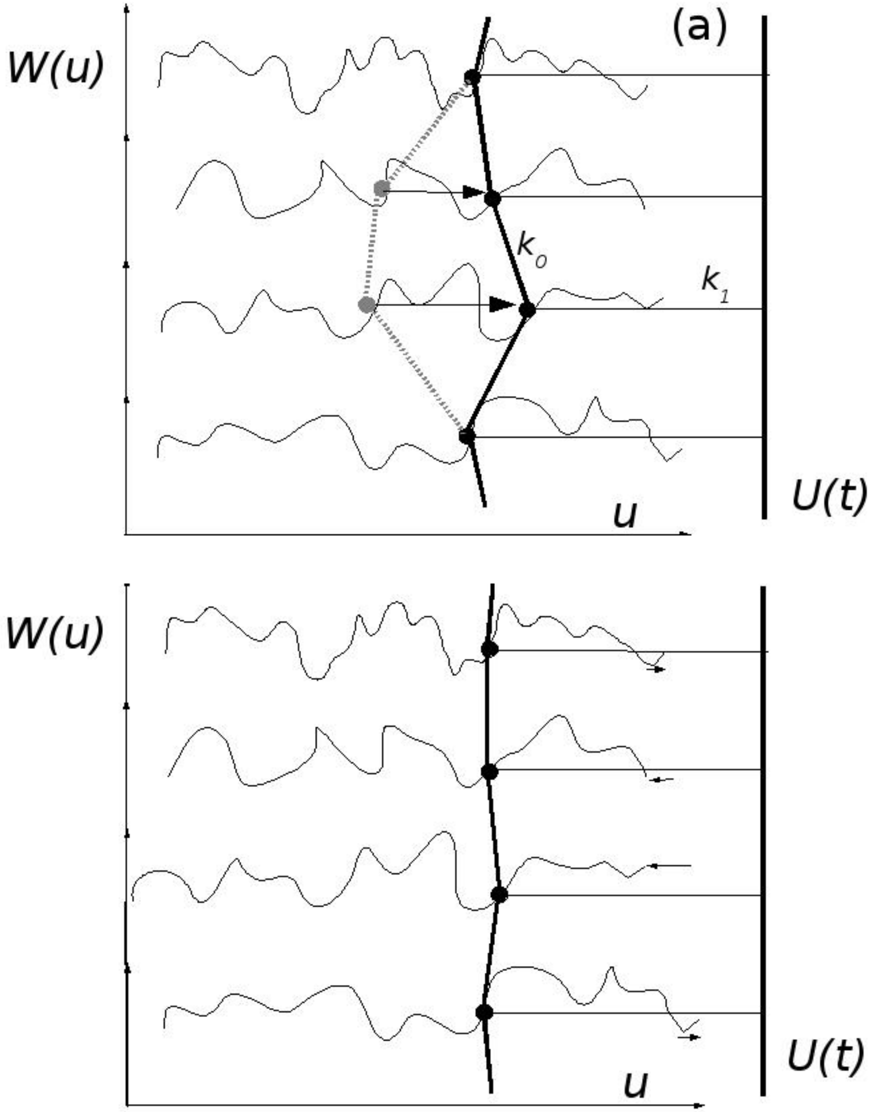
$$\frac{du_{i,j}}{dt} = -\lambda \frac{\delta E}{\delta u_{i,j}}$$



No clustering of events

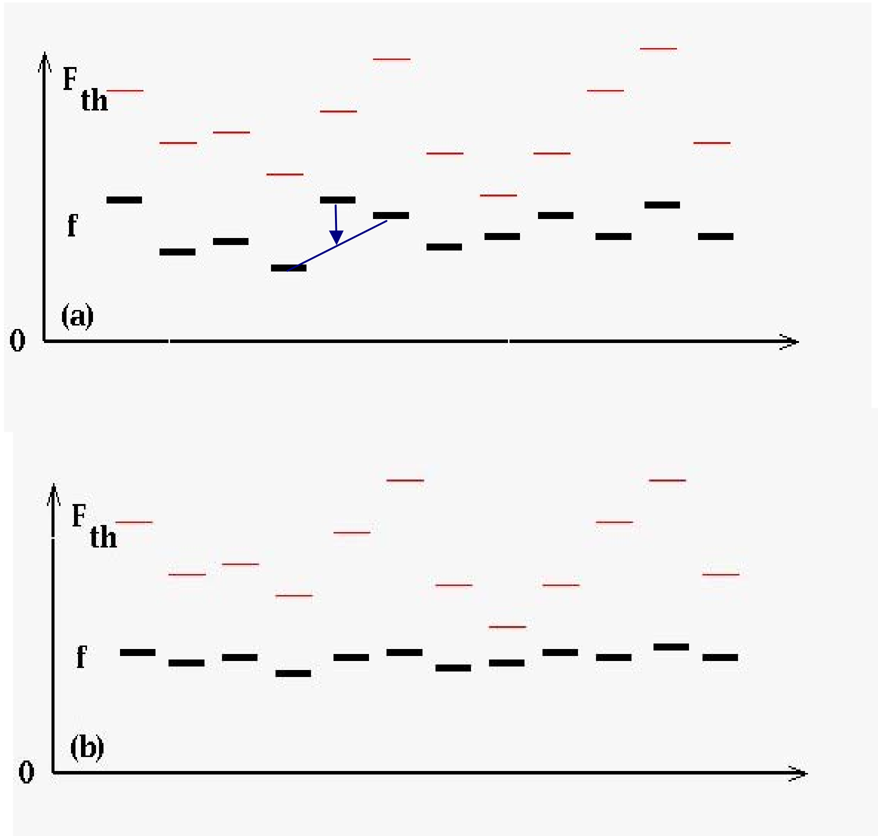
Trivial frictional properties

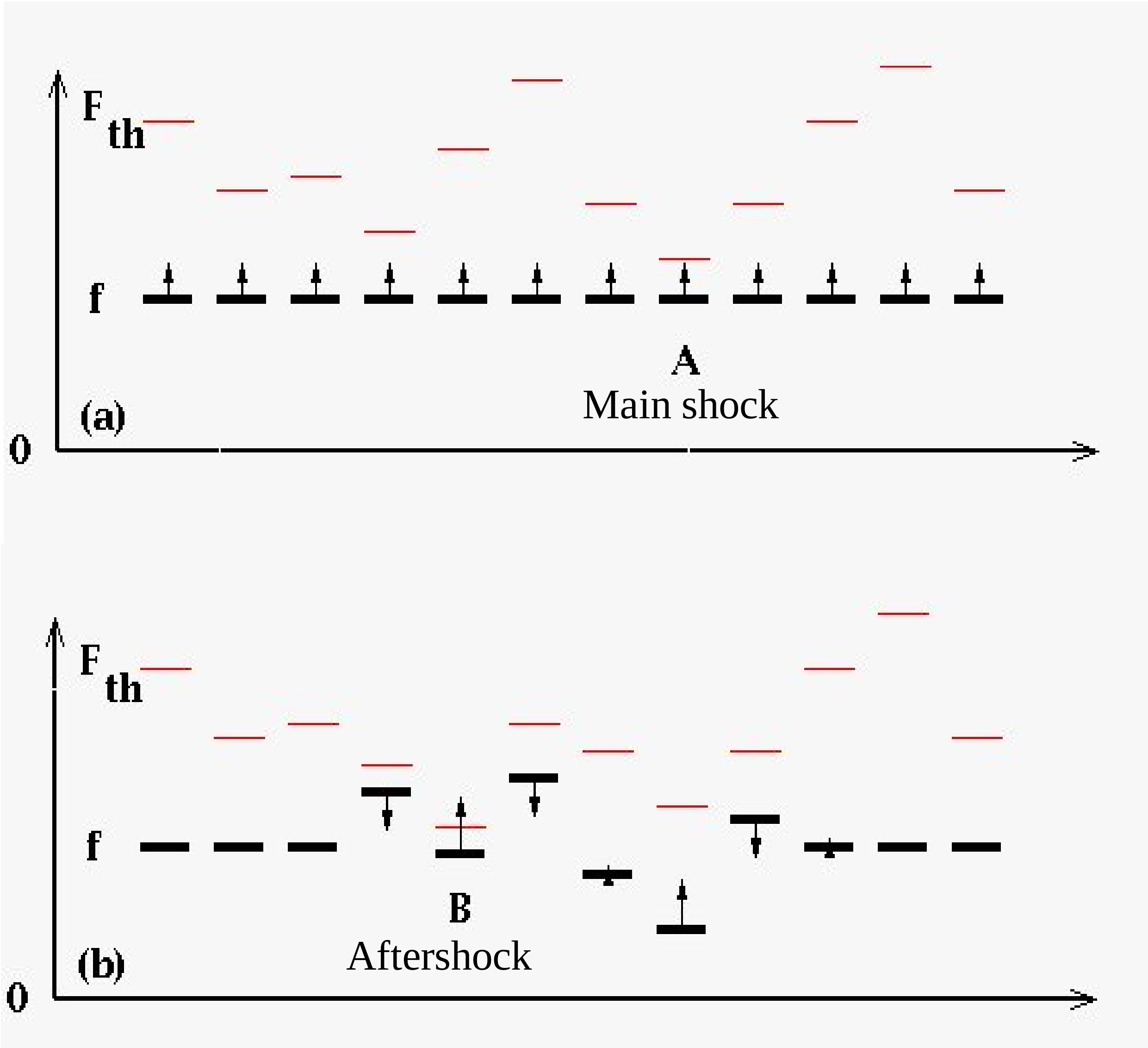
A time dependent mechanism (independent of Tectonic Loading) has to be included

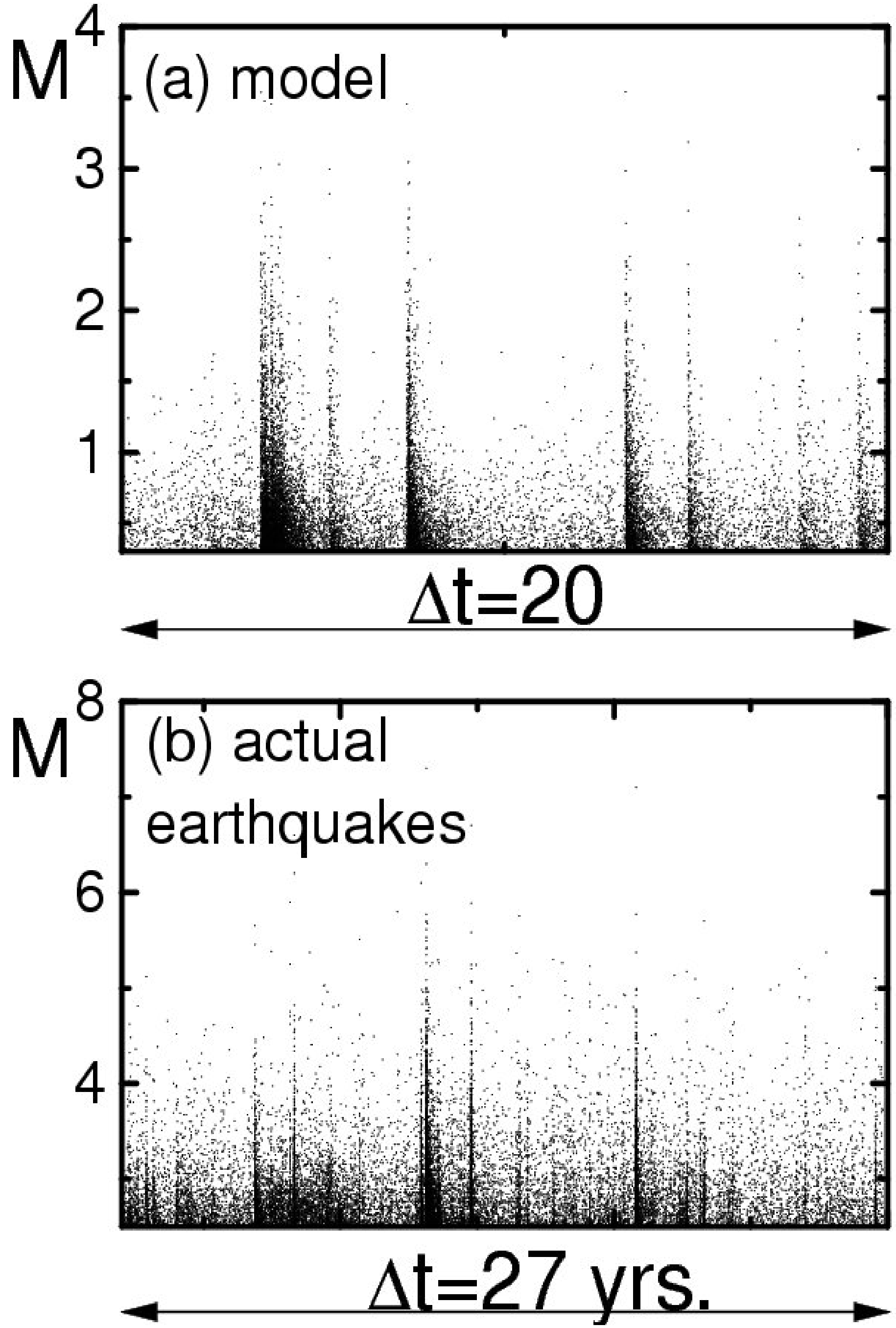


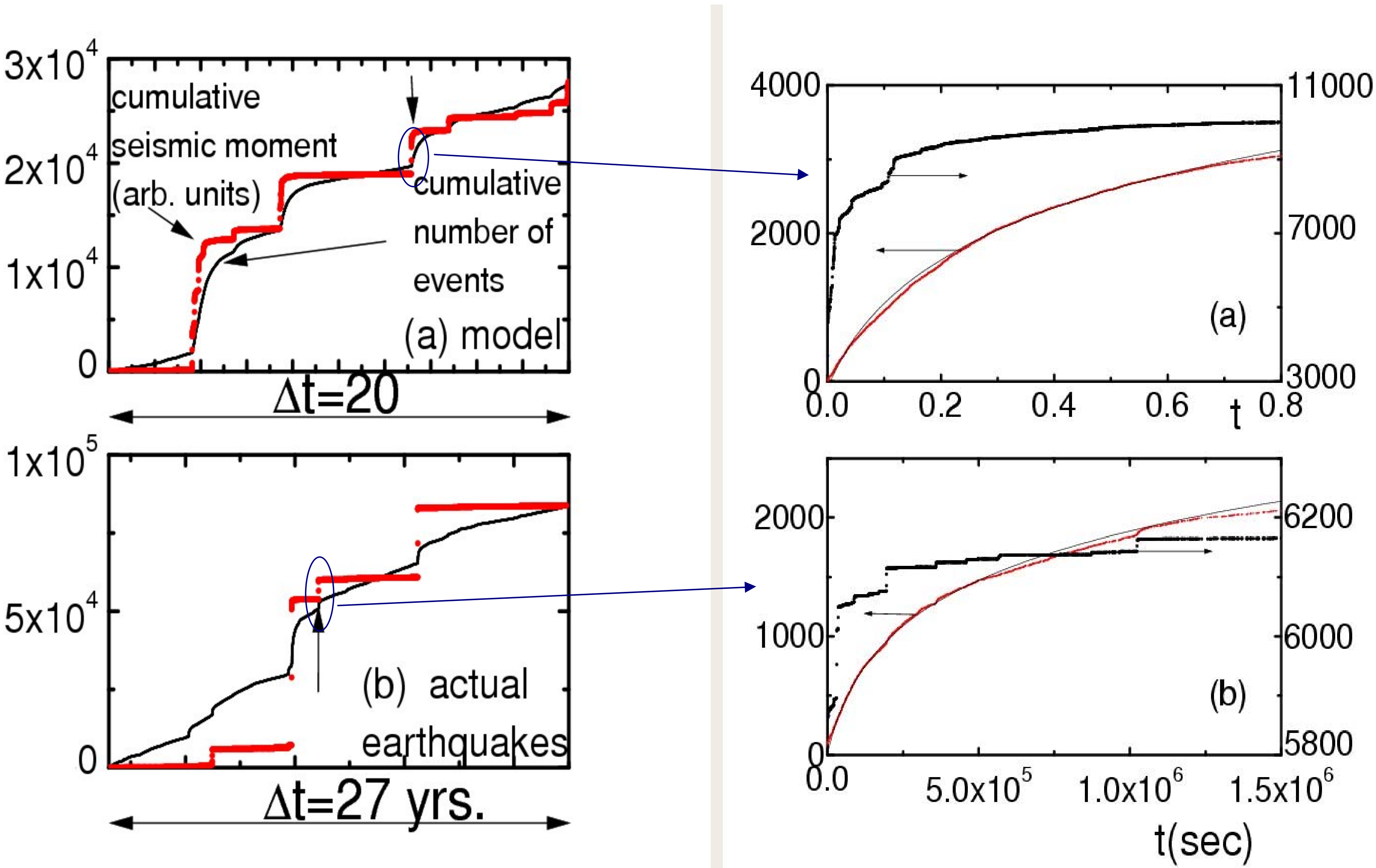
$$\sum_{i,j} W_{i,j}(u_{i,j}) \rightarrow \sum_{i,j} W_{i,j}(u_{i,j} - u^0_{i,j})$$

$$\frac{du^0_{i,j}}{dt} = R\nabla^2 \frac{\delta E}{\delta u^0_{i,j}}$$

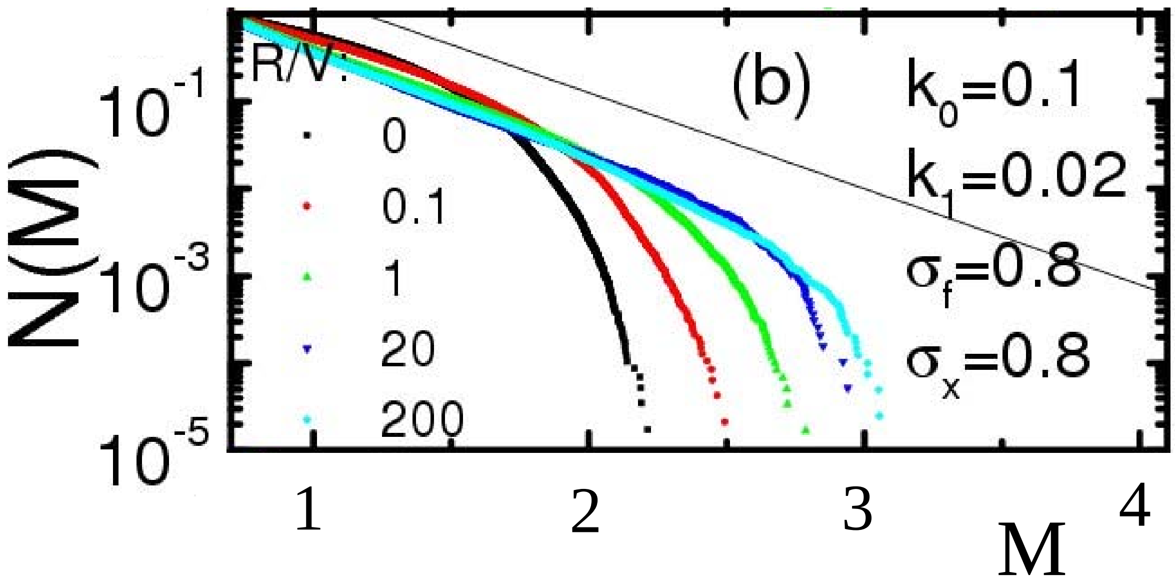



F th
f
A
Main shock
(a)
0
F th
f
B
Aftershock
(b)
0

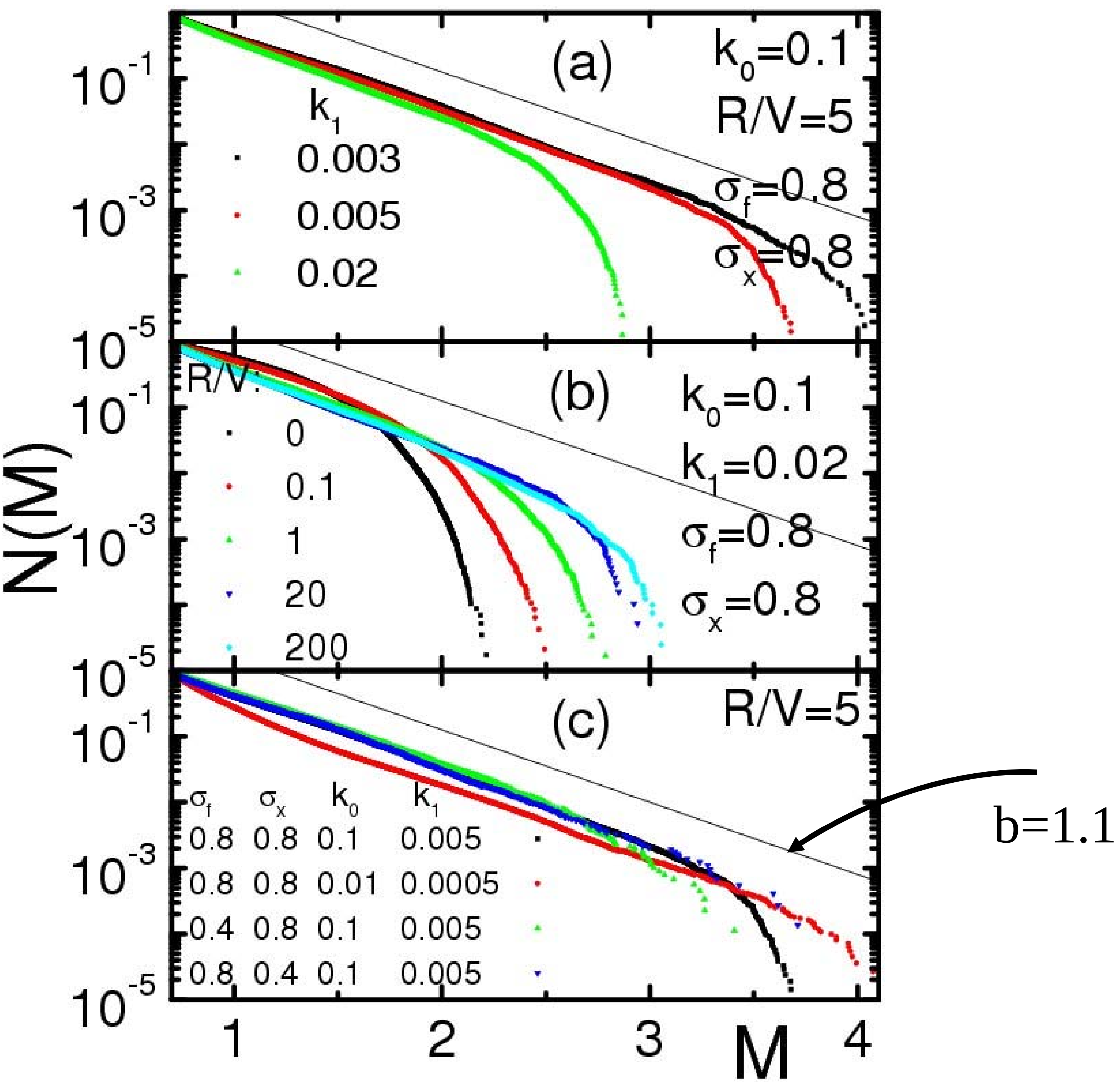

M
(a) model
4
3
2
1
Δt=20
M
(b) actual
earthquakes
8
6
4
Δt=27 yrs.



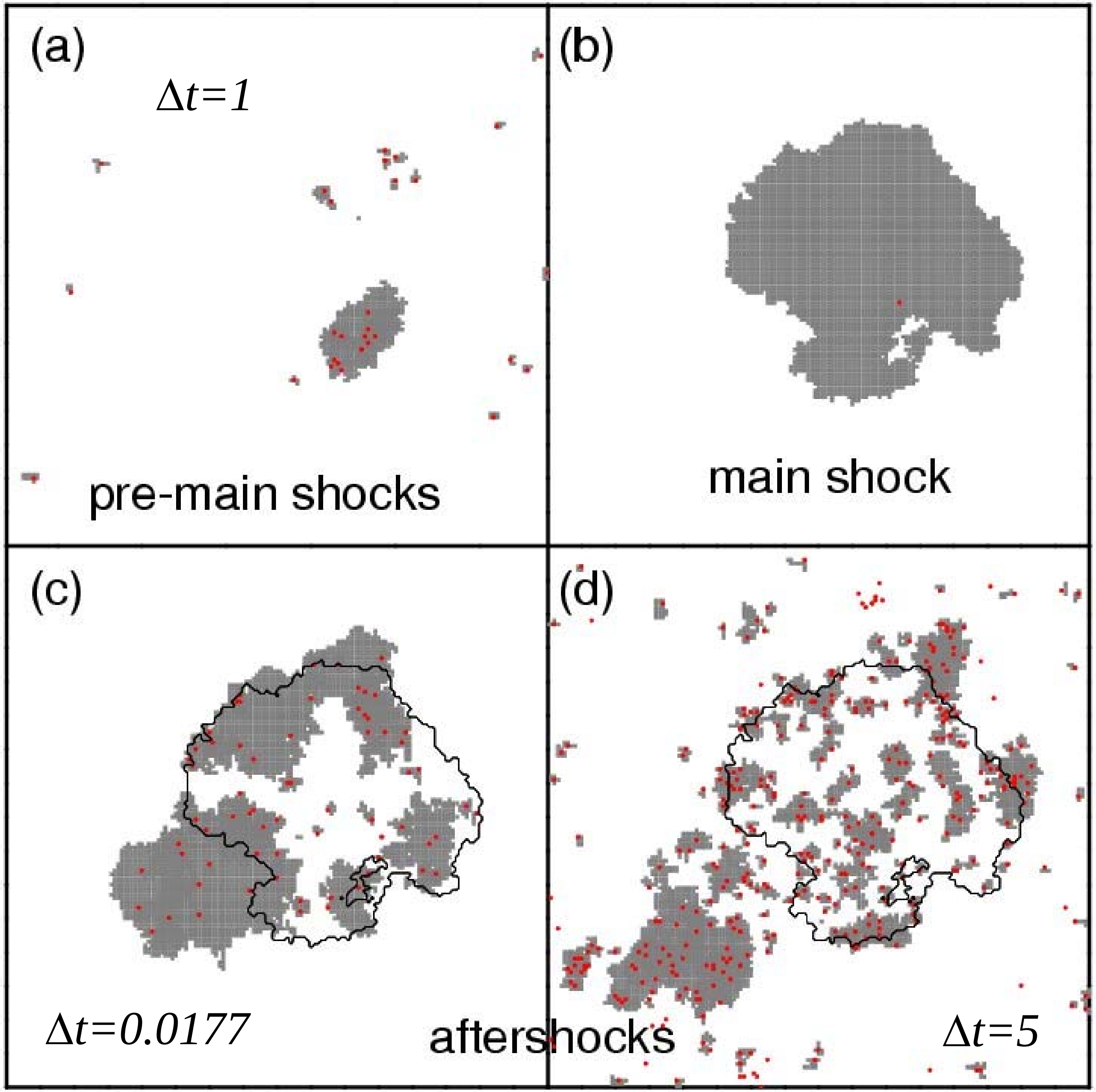
3x10^4
2x10^4
1x10^4
0
cumulative
seismic moment
(arb. units)
cumulative
number of
events
(a) model
Δt=20
1x10^5
5x10^4
0
(b) actual
earthquakes
Δt=27 yrs.
4000
2000
0
11000
7000
3000
(a)
0.0
0.2
0.4
0.6
t
0.8
2000
1000
0
6200
6000
5800
(b)
0.0
5.0x10^5
1.0x10^6
1.5x10^6
t(sec)



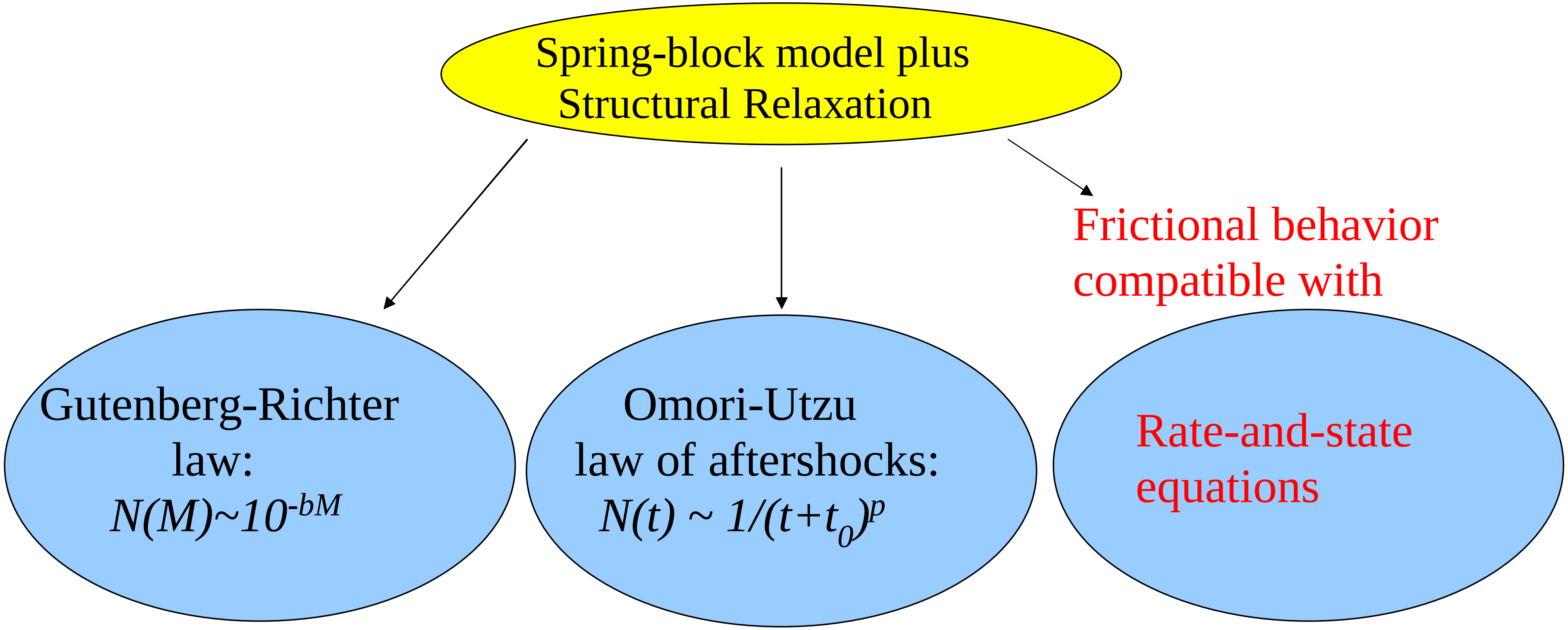
N(M)
10^{-1}
10^{-3}
10^{-5}
R/V:
0
0.1
1
20
200
(b)
k_0=0.1
k_1=0.02
σ_f=0.8
σ_x=0.8
1
2
3
4
M



(a)
k0=0.1
R/V=5
σf=0.8
σx=0.8
k1
0.003
0.005
0.02
(b)
k0=0.1
k1=0.02
σf=0.8
σx=0.8
R/V:
0
0.1
1
20
200
(c)
R/V=5
σf σx k0 k1
0.8 0.8 0.1 0.005
0.8 0.8 0.01 0.0005
0.4 0.8 0.1 0.005
0.8 0.4 0.1 0.005
b=1.1
N(M)
M



(a)
Δt=1
pre-main shocks
(b)
main shock
(c)
(d)
Δt=0.0177
aftershocks
Δt=5


Spring-block model plus Structural Relaxation
Gutenberg-Richter law: $N(M) \sim 10^{-bM}$
Omori-Utzu law of aftershocks: $N(t) \sim 1/(t+t_0)^p$
Frictional behavior compatible with
Rate-and-state equations


See you on Friday!